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# **SYNTHESIS AND CHARACTERIZATION OF InTiP AND InTlAs**

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*FINAL REPORT*  
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## 1.0 Objectives

The purpose of this program was to study the synthesis and material properties of InTlP and InTlAs for IR applications. The tasks are described in the following list.

### 1. *Growth and stability of InTlP and InTlAs*

Initial growth experiments will be conducted using elemental Tl and  $\text{PH}_3$  or  $\text{AsH}_3$ . Layers deposited on (100) semi-insulating InP or undoped InAs substrates will be characterized by Nomarski optical microscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic force microscopy (AFM), secondary ion mass spectroscopy (SIMS) and Hall effect measurement. Powder x-ray diffraction (XRD) and 5-crystal XRD will be used to determine lattice constant as a function of Tl content for both materials. Growth parameters such as V/III ratio, Tl source and growth temperature will be optimized with respect to structural and electrical quality. In particular, the maximum Tl content which can be obtained without inducing nucleation of metallic Tl droplets will be determined. The relative thermal stabilities of the ternary alloys will be determined as a function of Tl content by monitoring the surface structure and desorption products as functions of temperature and group V flow.

### 2. *Doping of InTlP*

The alloy system which yields the most promising properties for use as an IR material as determined from Task 1 will be investigated further by examining the electrical behavior of various impurities. Both unintentionally and intentionally doped samples with various Tl mole fractions will be investigated with variable temperature Hall measurement, to determine the activation energies of intrinsic impurities or defects, and SIMS and AES, to attempt to correlate the electrical centers with impurity species or stoichiometric variations. Results will be compared with theoretical predictions of impurity levels calculated at SRI. Sn, Te and Si will be explored as n-type dopants and Mg will be investigated as a p-type dopant. Ohmic contact resistances using AuGe and TiPtAu will also be determined as a function of doping level.

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### 3. Junctions

Once controllable n- and p-type doping and acceptable Ohmic contacts are established, junction quality will be evaluated. Diode characteristics of homojunctions of various Tl mole fractions will be evaluated first followed by similar experiments in InTlP/InP or InTlAs/InAs heterojunctions. SIMS analysis will also be performed in order to determine dopant abruptness and electrical quality.

### 4. Interfacial Control

The ability to reduce strain and/or dislocation densities in the InTlP through the use of graded  $\text{In}_{1-x}\text{Tl}_x\text{P(As)}$  layers and InTlP(As)/InP(As) superlattices will be investigated. Films will be characterized using the same techniques as described previously. Interfacial abruptness will be optimized by examining quantum wells grown under various conditions with TEM and PL. The optimum interface will be achieved by optimizing the switching sequence and growth interruption time. Thermal stability will be evaluated by annealing the structures both in-situ and ex-situ, using rapid thermal annealing, and characterizing the layers with TEM and XRD. Diffusion studies in both homojunctions and heterojunctions will be studied using similar annealing and characterization. In these structures, SIMS and C-V profiling will be used to determine the carrier concentration profiles for correlation with the matrix and dopant distributions.

## 2.0 Growth of Tl-Containing Phosphides

It was determined that low growth temperatures are needed to produce material which contains Tl. Under no circumstances could a phase containing In, Tl and P or Tl and P be formed during attempted epitaxy. Depending upon growth temperature, either a defective In structure was obtained with no evidence of Tl incorporation or, at temperatures less than 400°C, an InP matrix with Tl droplets dispersed throughout. Attempts to deposit TIP resulted in formation of Tl droplets atop the InP substrate. For both the Tl-P and In-Tl-P attempts, exposure to air resulted in rapid oxidation of the metallic Tl as determined by SEM, EMPA (electron microprobe analysis) and XRD.